Multifunction Phased Array Radar: Technical Synopsis, Cost Implications, and Operational Capabilities

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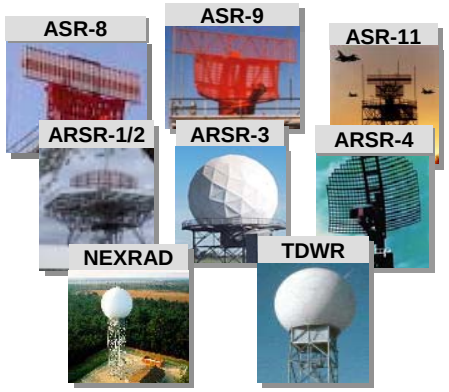
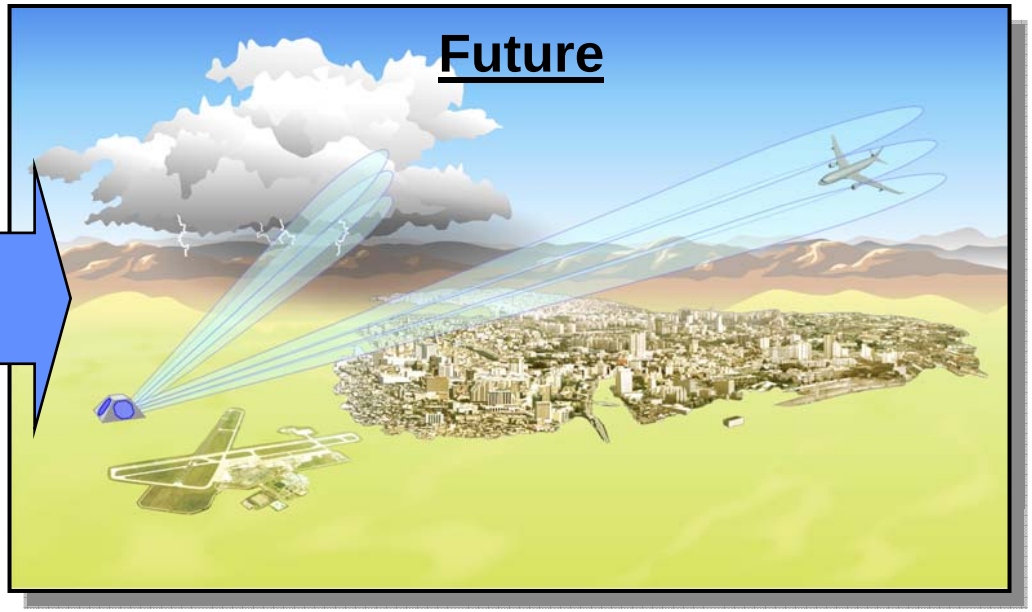
National Air Surveillance Infrastructure

Today



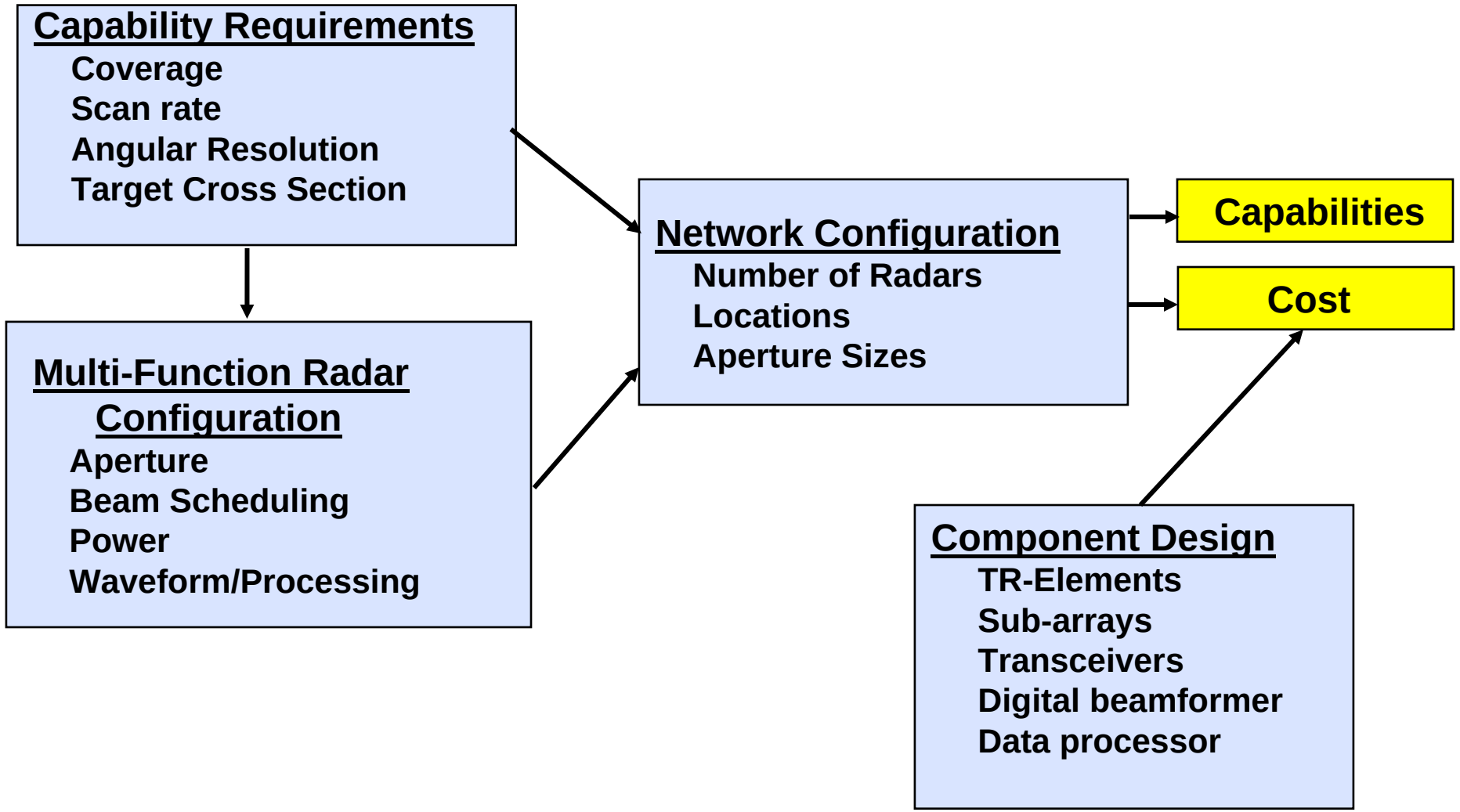
- 3 genuses, 8 species
- Mission-specific designs
- Operated/maintained by FAA and NWS. Also used to support DoD/DHS missions

Future



- Multi-mission active electronically scanned array radar
- Consolidates life-cycle support infrastructure
- Eliminates key single-point of failure items (mechanical drive, TX)
- Improved operational capabilities

Multi-Function Phased Array Radar Concept Definition Study



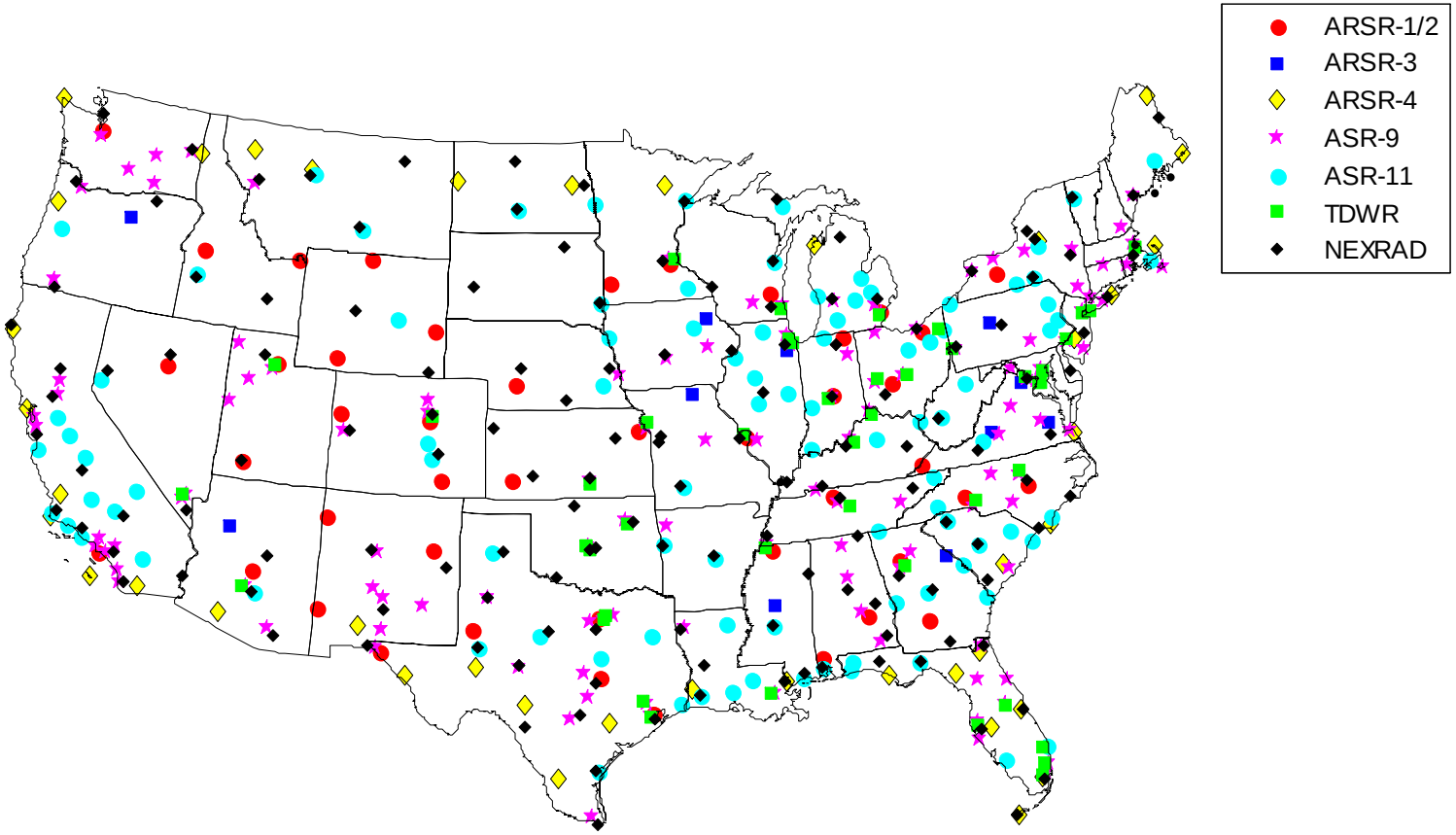
Current Surveillance Radar Capabilities

	Maximum Range for Detection of 1m² Target	Required Coverage		Angular Resol.		Waveform*	Scan Period
		Range	Altitude	Az	El		
Terminal Area Aircraft Surveillance (ASR-9/11)	60 nmi	60 nm	20,000'	1.4°	5°	>18 pulses PRI ~ 0.001 sec	5 sec
En Route Aircraft Surveillance (ARSR-4)	205 nmi	250 nm	60,000'	1.4°	2.0°	>10 pulses PRI ~ 0.001 sec	12 sec
Terminal Area Weather (TDWR)	212 nmi	60 nmi	20,000'	1°	0.5°	~50 pulses PRI ~ 0.001 sec	180 sec
En Route Weather (NEXRAD)	225 nmi	250 nmi	50,000'	1°	1°	~50 pulses PRI ~ 0.001 sec	>240 sec

Weather surveillance drives requirements for radar power and aperture size

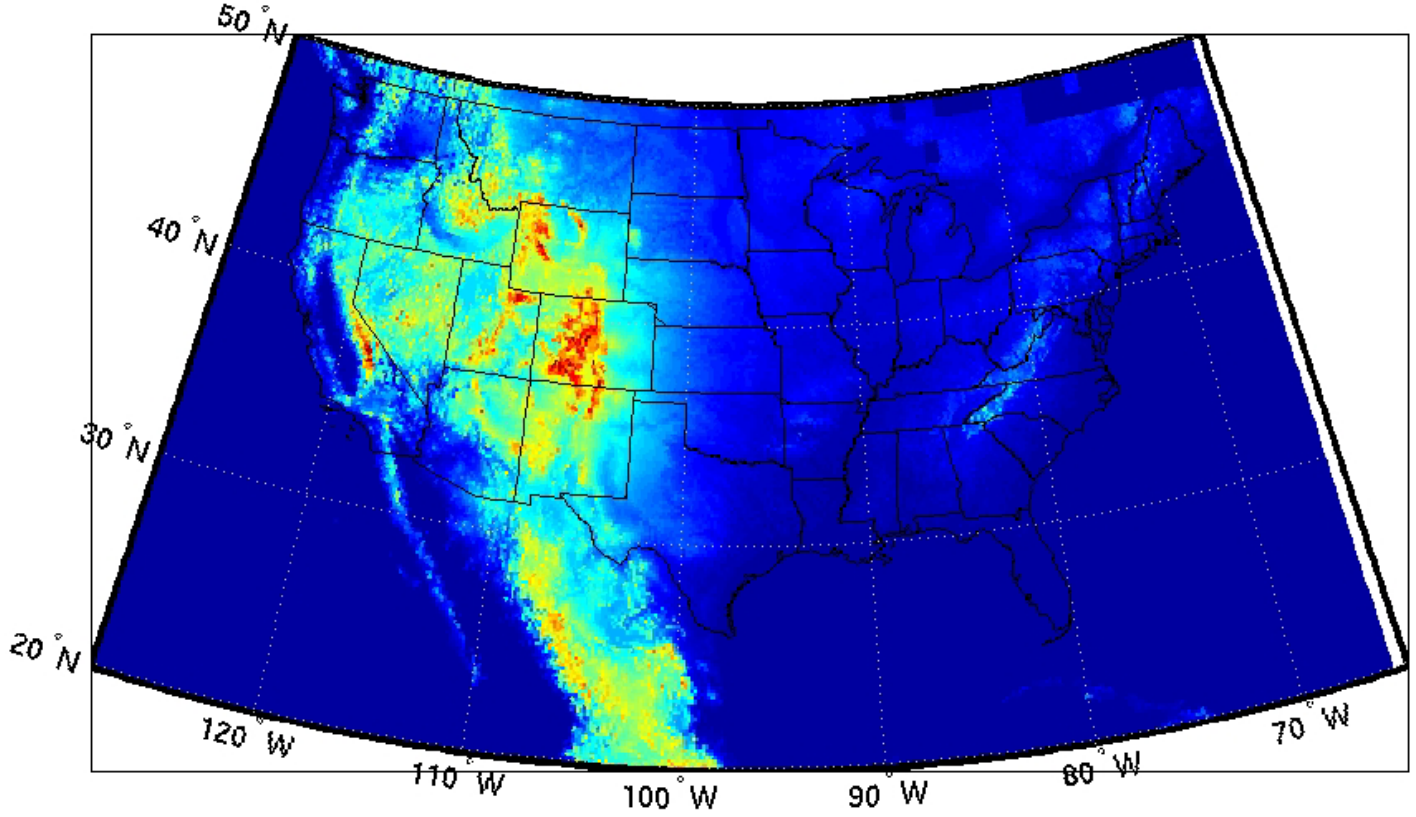
Non-cooperative aircraft surveillance can be provided using active array technology to achieve necessary volume scan update rates

National Surveillance Radar Networks



Airspace Coverage Analysis

- **U.S. airspace data-base developed to evaluate MPAR network coverage (line of sight, minimum detectable target cross section, spatial resolution). Minimum required coverage based on current radar networks.**



High resolution (100 m) terrain data

CONUS Coverage

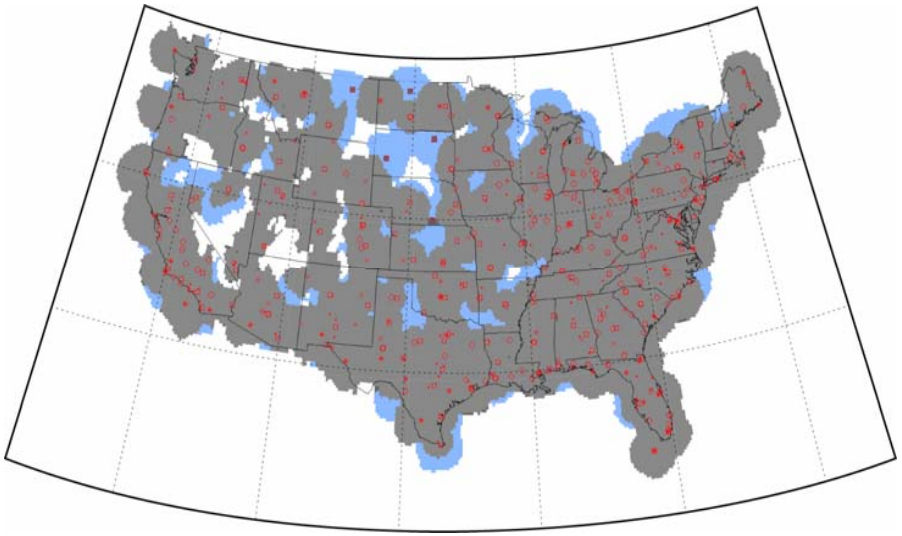
Current Air Surveillance Coverage

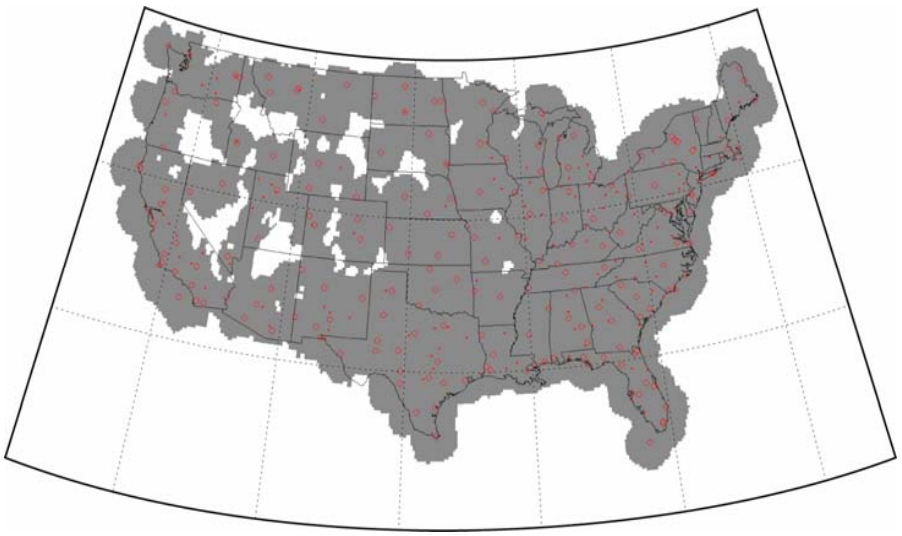
510 Total Radars, 8 types

Multifunction Radar Coverage

334 Total Radars, 1 type*

35% reduction





Blue: weather radars only

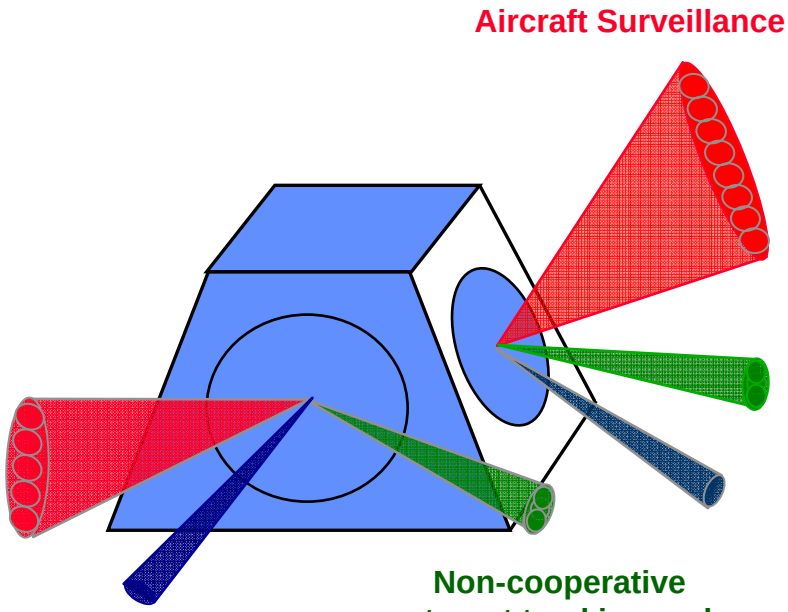
***Two tiered: Full-size MPARs and terminal-area MPARs**

@ 5000 ft AGL

Outline

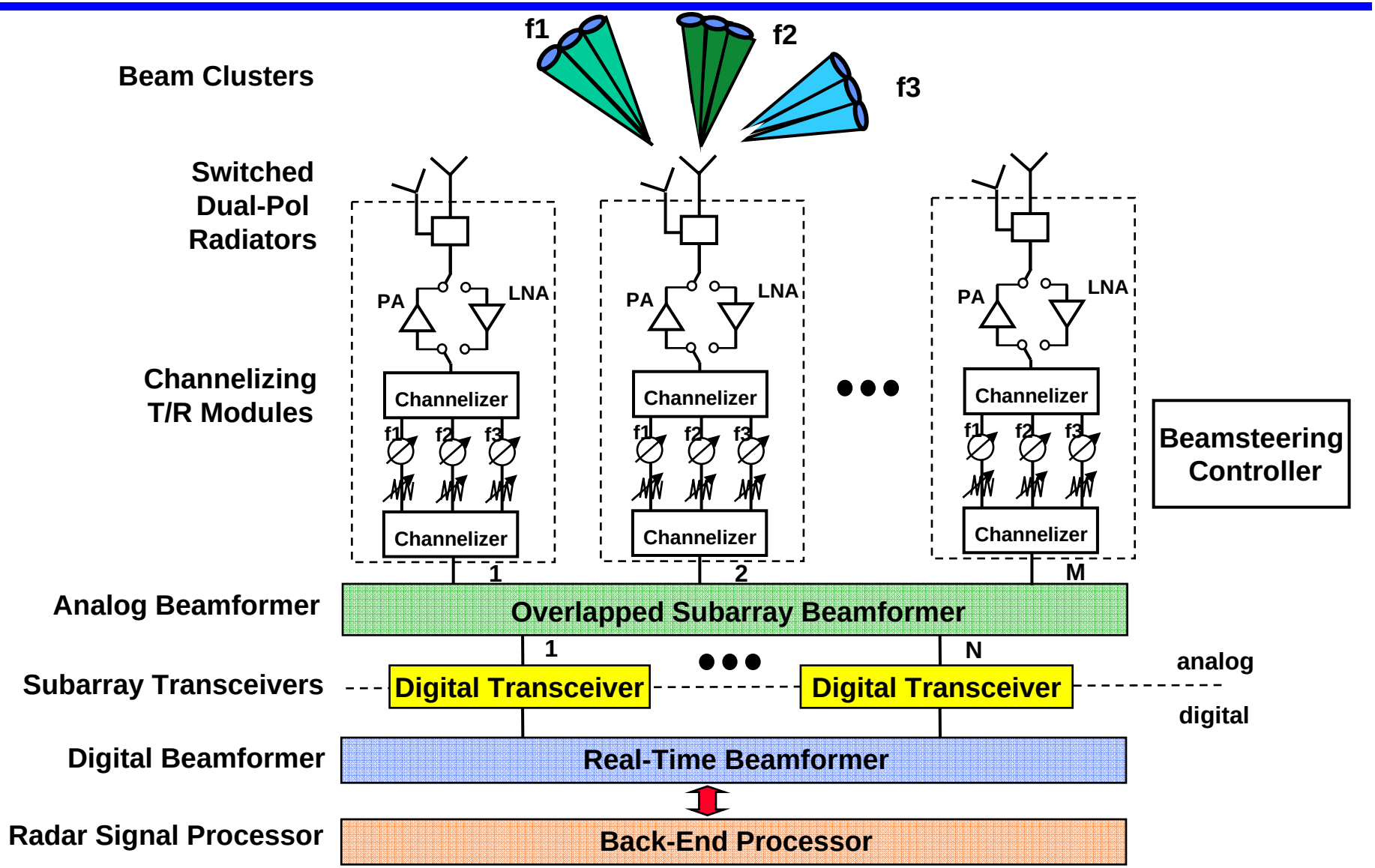
- Required capabilities
- MPAR concept design
  - Architecture
  - Transmitter peak power
- Capability improvements
  - Weather surveillance
  - Non-cooperative aircraft surveillance
- Cost model

Concept MPAR Parameters



- **Transmit/Receive Modules**
  - Wavelength: 10 cm (2.7–2.9 GHz)
  - Bandwidth/channel: 1 MHz
  - Frequency channels: 3
  - Pulse length: 1–100 μs
  - Peak power/element: 1–10 W
- **Active Array (planar, 4 faces)**
  - Diameter: 8 m
  - TR elements/face: 20,000
  - Dual polarization
  - Beamwidth: 0.7° (broadside)
    1.0° (@ 45°)
  - Gain: > 46 dB
- **Overlapped sub-arrays support parallel receive pencil beams (~50 total)**

MPAR Architecture

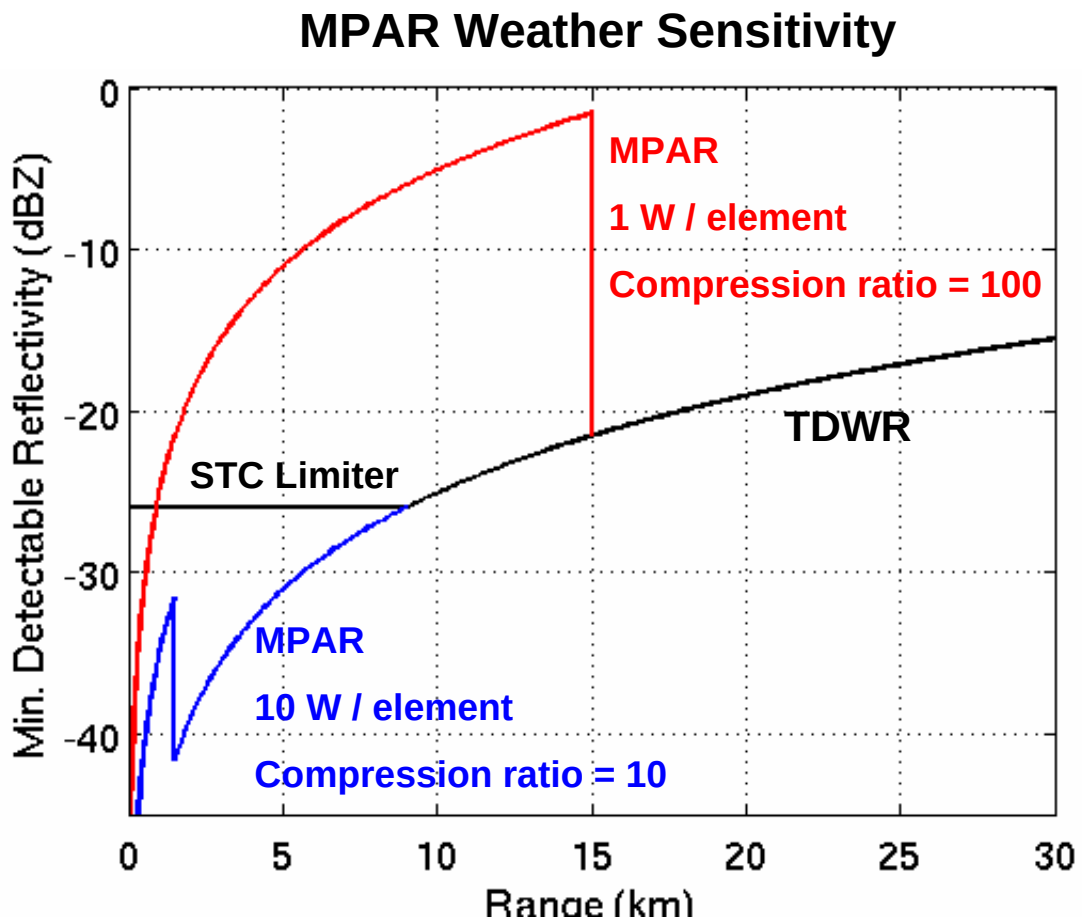


TR Module Peak Power Considerations

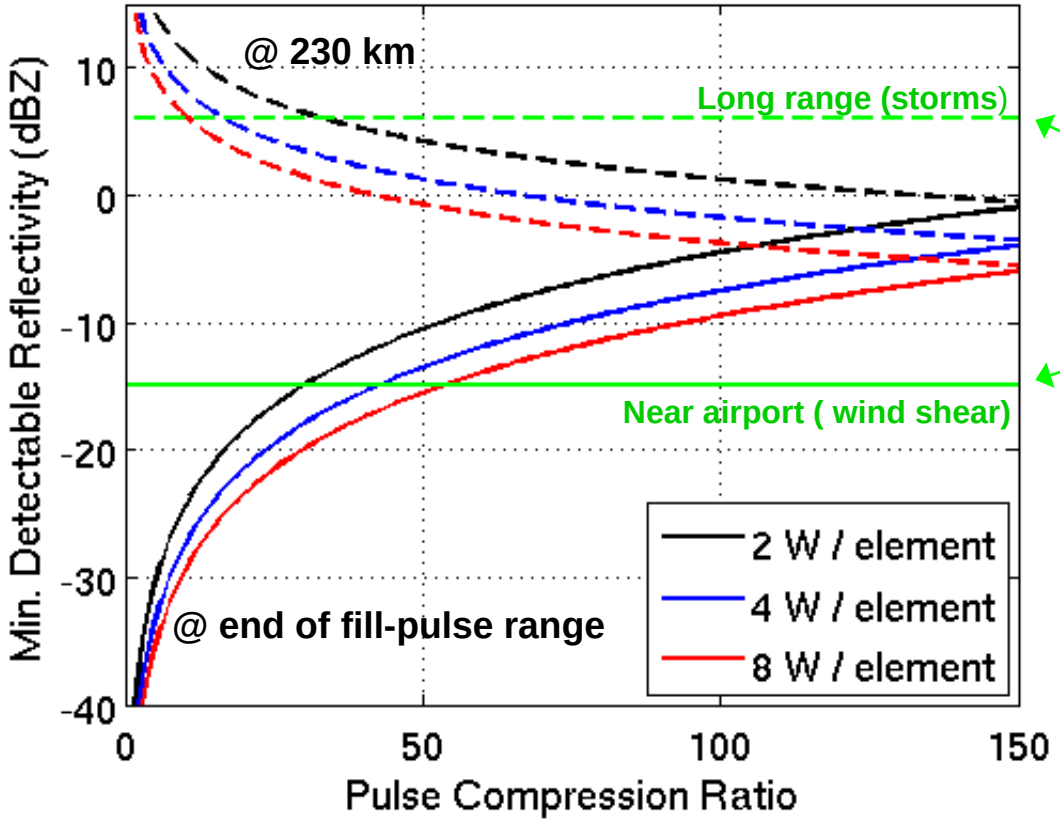
- Sensitivity ~ $P_p N^3 \tau$
- TR Module cost ~ P_p

$\Rightarrow$ **Keep P_p small, increase N and lengthen τ as needed**

- Utilize pulse compression for range resolution
- Long τ requires short "fill" pulse for close-range terminal-area surveillance



MPAR Minimum Detectible Weather Reflectivity versus Pulse Compression Ratio



Derived requirements based on TDWR, NEXRAD capabilities

2W peak power TR element with 30 μs long-pulse and 1 μs fill-pulse meets sensitivity requirements

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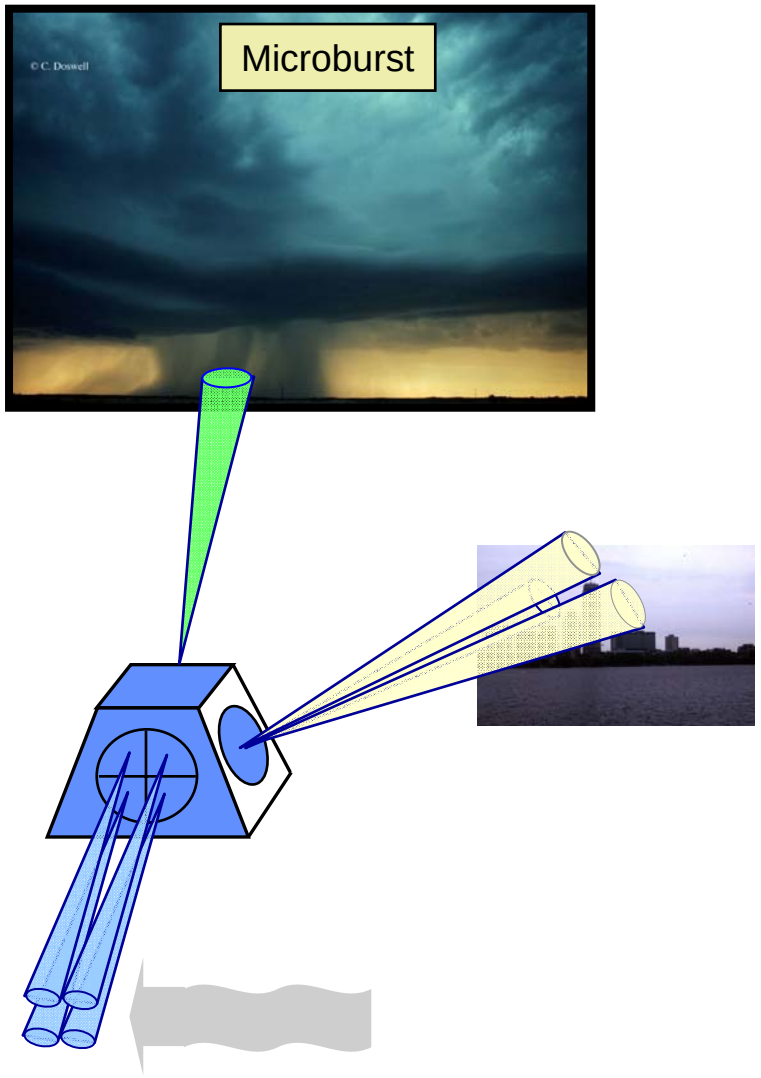
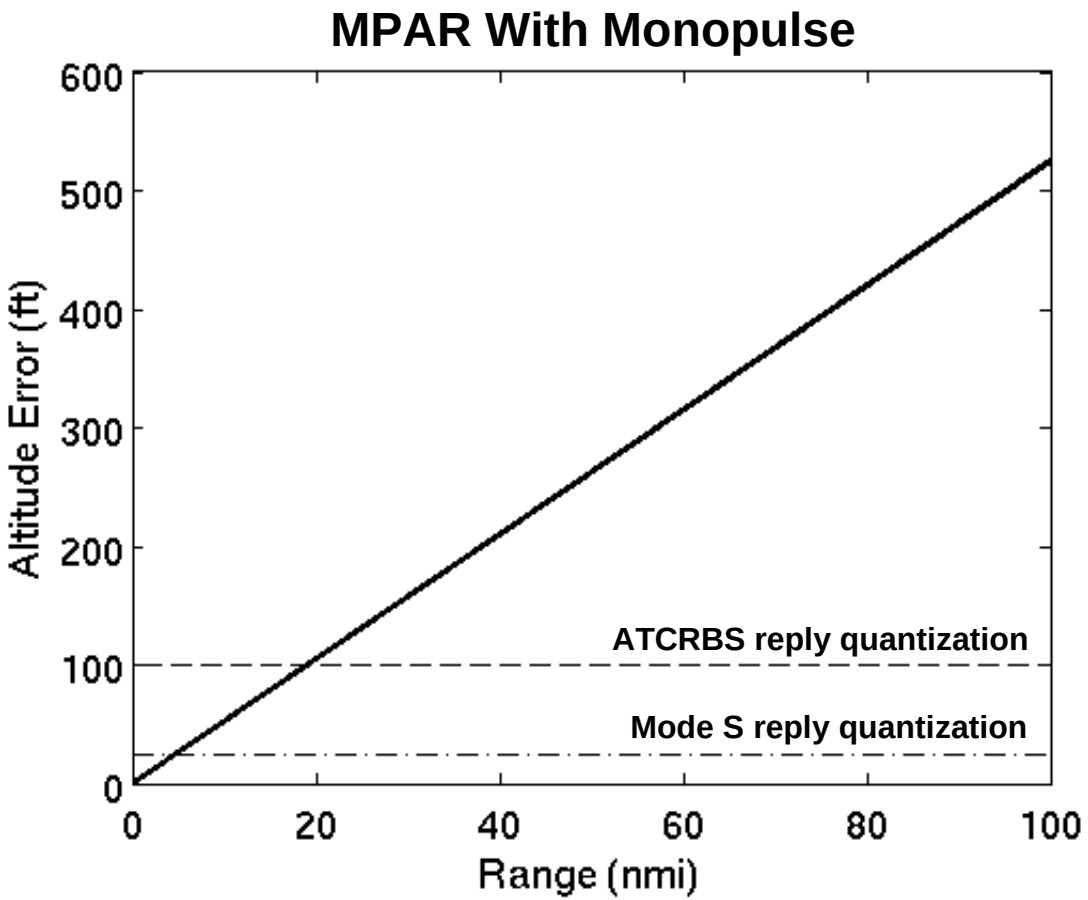
Weather Surveillance Capability Improvements

- **Rapid and adaptive scanning**
  - Quicker update on fast-evolving hazards
  - Improved time-resolution for cloud-scale NWP models
- **Beam steering, shaping, and nulling**
  - Reduced clutter and blockage
- **Spaced antenna interferometry**
  - Cross-beam velocity, shear, and turbulence estimation



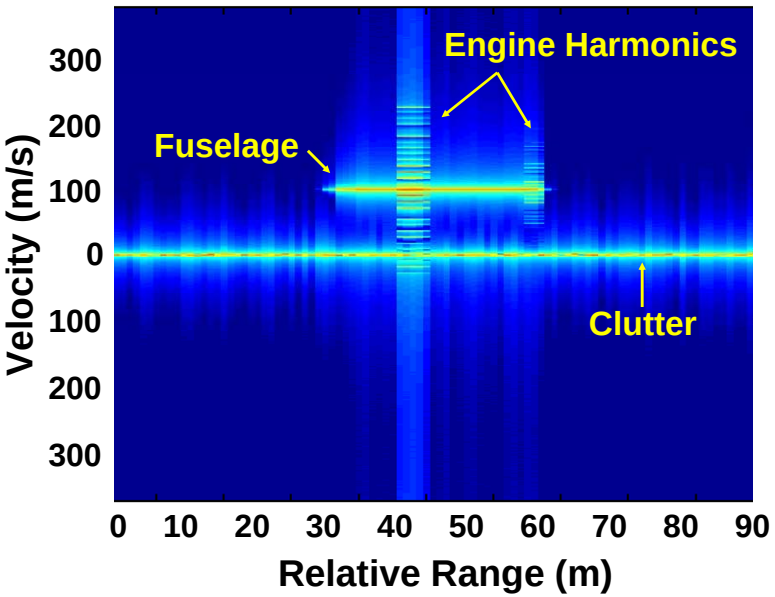
Non-cooperative Target Surveillance: 3D Tracking

- Current FAA primary radars do not measure target altitude
- MPAR would provide height measurement for non-cooperative targets
  - Reduces false-track initiation substantially
  - Improves capability to monitor separation for non-cooperative targets



Non-cooperative Aircraft Surveillance: Target ID

Notional HDV+HRR Spectral ID Image



Notional MPAR Modes Including Target ID

Mode	PRF (kHz)	Bandwidth (MHz)	Range Resolution (m)	Doppler Resolution (Hz)	Integration Time (ms)
Wide Area Surveillance (WAS)	1	1	150	20	50
High Doppler Velocity (HDV)	15	1	150	2	500
High Range Resolution (HRR)	1	200	1	10	100
HDV + HRR	15	200	1	2	500

- Target ID (HDV and HRR) modes cannot operate concurrently with Wide Area Surveillance modes
- Could be used intermittently during WAS without significant impact on radar timeline

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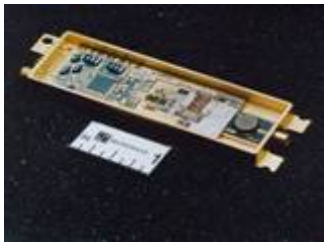
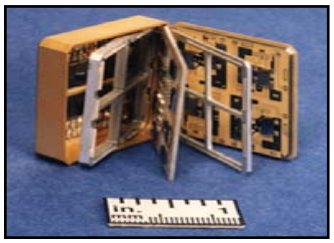
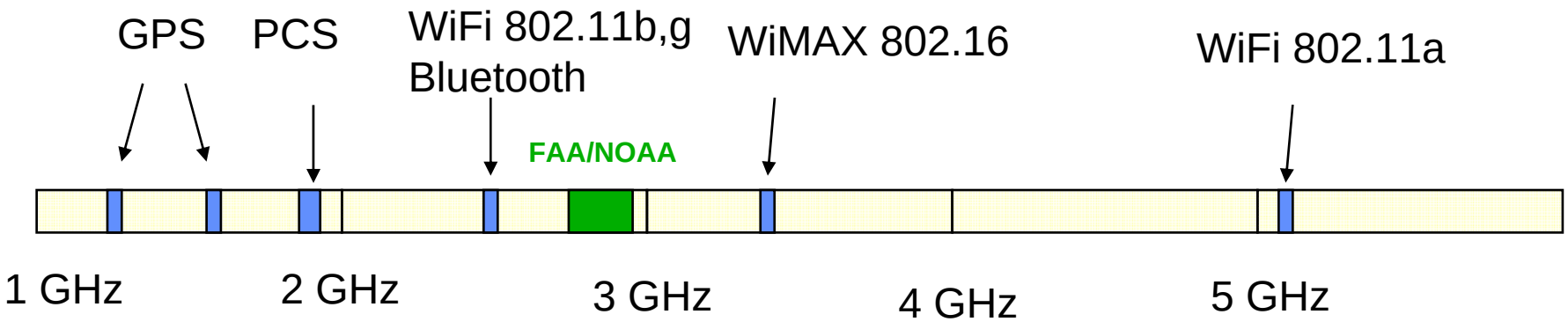
Military TR-Module Evolution

Separate T and R	Single T/R	Quad-Pack T/R	64 Element T/R Tile
			
F/A-22 (1995)	***F-15 (V)2 (2000)***	***F/A-18 E/F (2005)***	***Space Based Radar (Prototype)***

~$2000 / element (1990) → Increasing Levels of Integration → ***~$200 / element (2010)***

Cost drivers are requirements for high-power, high-bandwidth, ruggedization and small-lot acquisition

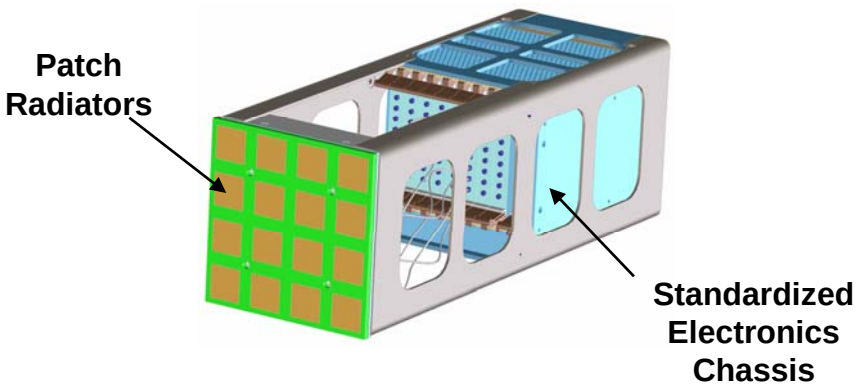
Wireless Communication Bands



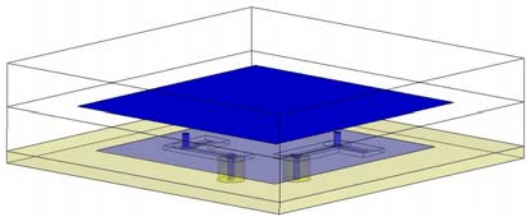
- **Many low-cost WiFI/WiMAX devices cover FAA/NOAA surveillance band**
- **Projected 2008 sales volume $3.6B**

Lincoln MPAR Subsystem Design (Based on WiFi Technology)

Scalable Brick Architecture

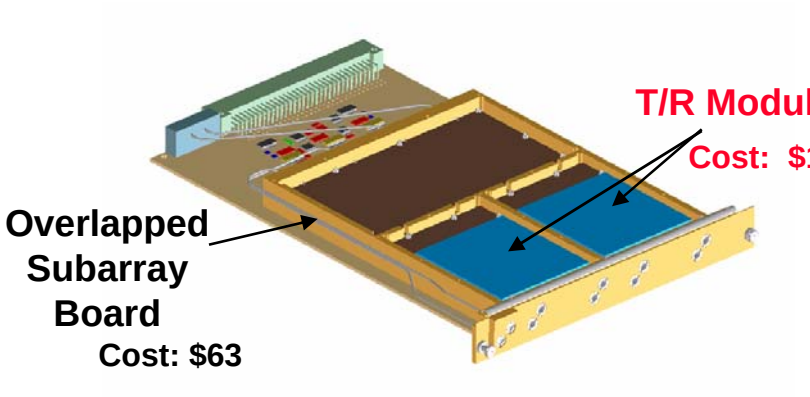


Dual Polarized Stacked Patch Antenna

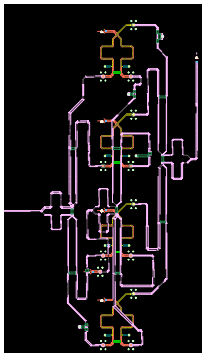


Cost: $1.25

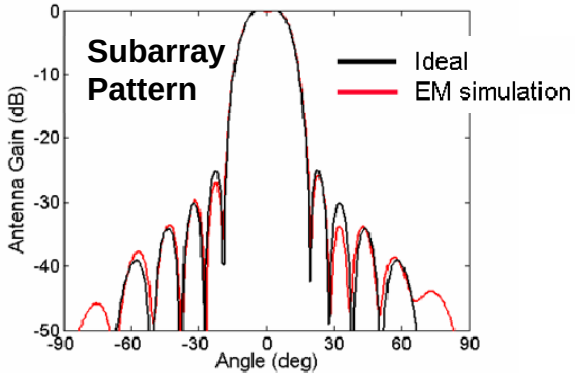
Ultra-Low Cost Dual Mode T/R Module



Overlapped Subarray Beamformer



Board Layout



MPAR Cost Model

Equivalent Parts Cost per TR-Element

Component	Pre-Prototype	Second Generation Full-Scale Prototype
Antenna Element	$1.25	$1.25
T/R Module	$14.00	$14.00
Power, Timing and Control	$18.00	$18.00
Digital Transceiver	$12.50	$6.25
Analog Beamformer	$63.00	$15.00
Digital Beamformer	$18.00	$8.00
Mechanical/Packaging	$105.00	$25.00
RF Interconnects	$163.00	$40.00

Parts Cost Summary based on detailed sub-system designs:

Full-aperture MPAR (NEXRAD, TDWR, ARSR, ASR capability)	$11 M
"Terminal" MPAR (ASR capability)	$ 3 M

Summary

- MPAR “requirements” derived from current surveillance radar capabilities
- Detailed conceptual design developed
  - Radar configuration and CONUS network
  - Allows for definition of surveillance capabilities and assessment of costs
- Ongoing primary radar “alternatives analysis” effort
  - Quantify surveillance benefits vis a vis legacy configuration
  - Compare life-cycle costs